Inelastic bouncing of cold atoms on evanescent-wave mirrors

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Evanescent waves (EW) are widely used as mirrors for cold atoms [1]. When optical transitions between internal atomic states are involved, bouncing on *inelastic* EW mirrors can provide cooling [2]. Another application of inelastic mirrors, using the short EW decay length, is to load an optical trap in the vicinity of a surface [3]. In such schemes, bounces of atoms on the EW are interrupted at the motional turning point and atoms are *dissipatively* transferred into a trapped state by an optical pumping cycle. The final phase-space density of the trapped atoms can be significantly larger compared with the initially laser cooled atoms. This might open a way to create a low-dimensional optically trapped quantum gas [4].

Although photon scattering should be suppressed in atom optical applications with specularly reflecting EW mirrors, surface trap loading can be optimized by an adequately chosen scattering rate. Here we report on two experiments involving photon scattering.

In the first experiment we have investigated radiation pressure that is exerted by an EW mirror on bouncing atoms [5]. The motion in the direction normal to the surface is elastical. In the direction parallel to the surface we have observed radiation pressure. The EW was tuned to the "blue" with respect to a *closed* optical transition of ^{87}Rb ($5S_{1/2}(F=2) \to 5P_{3/2}(F'=3)$, linewidth $\Gamma/2\pi = 6$ MHz). The detuning δ ranged from $30-230\ \Gamma$. Atoms were released from a magneto-optical trap (MOT), located 6.6 mm above the EW mirror. The trajectories of bouncing atom clouds were analyzed by imaging the fluorescence of a resonant probe pulse. A time sequence of fluorescence images is shown in Fig. 1a. Due to radiation pressure the atoms rise with a horizontal velocity component after the bounce. We extract the number of scattered photons N_{scat} from the trajectories as a function of detuning δ and EW decay length ξ, the latter of which is shown in Fig. 1b. We observed N_{scat} ranging from 2-31 photons, in agreement with a simple two-level atom model, where the radiation pressure is given by $N_{scat} = \Gamma p_i \xi / \hbar\delta$. Here p_i is the incident vertical momentum of the atoms. The two-level model prediction and a correction for the excited state hyperfine structure of rubidium are also shown in the figure.

In a second experiment, we tuned the EW to the blue wing of an *open* optical transition ($F=1 \to F'=2$) in order to perform inelastic bounces. After release from the MOT, falling atoms were optically pumped into the $F=1$ ground state before they hit the mirror. In this case, atoms can undergo a Raman transition during the bounce and leave the mirror in $F=2$. The atoms are probed by absorption imaging. An image, taken 9 ms after the bounce, is shown in Fig. 1c. Since the light shift of the $F=2$ state in the EW potential is only about 15 % compared to that of the $F=1$ state, the vertical motion of atoms pumped to $F=2$

is effectively slowed down. Thus the rising cloud forms a dense sample close to the surface. Vertical density distributions of those atoms are shown in the figure for two choices of detuning. The high density at low height shows that the Raman transition takes place preferentially near the turning point of the bounce. The diffuse tail is a consequence of the stochastic nature of the transition.

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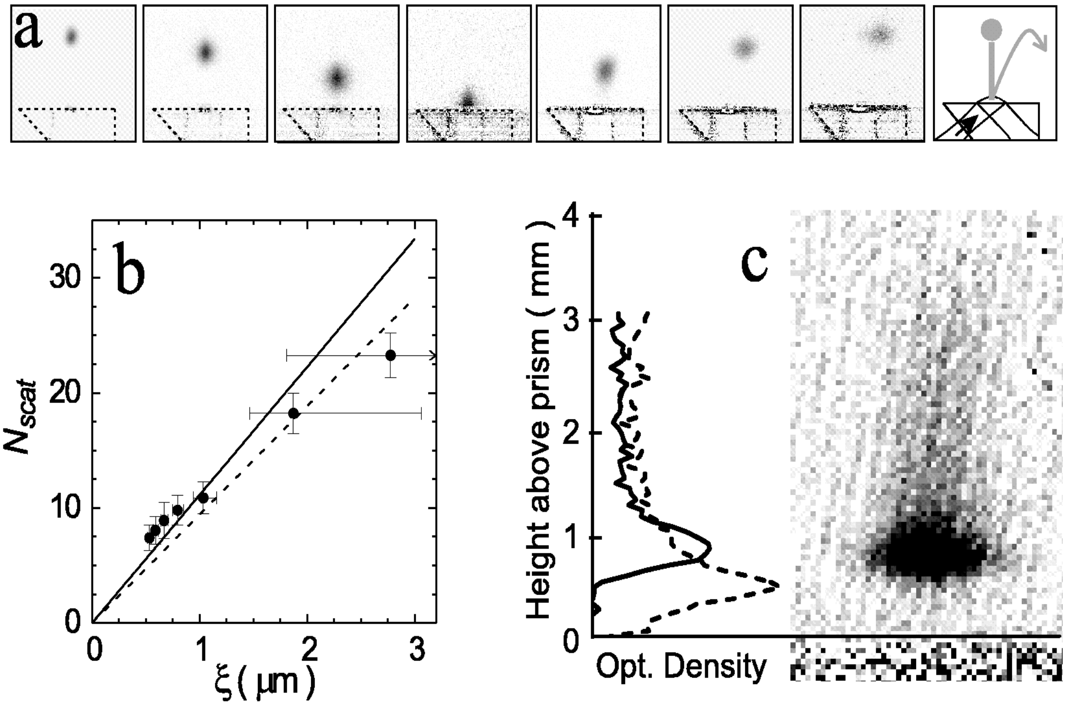

Figure 1: (a) Fluorescence images of bouncing atom clouds: the first image was taken 5 ms after release from the MOT; consecutive images have 10 ms incremental time delay. The last frame shows the configuration of MOT, prism (1 cm width) and EW. (b) Lateral radiation pressure on elastically bouncing atoms: average number of scattered photons N_{scat} per atom vs. EW decay length ξ. Also shown is the two-level model prediction (solid line) with a correction for the rubidium hyperfine structure (dashed line). (c) Absorption image and density profiles of inelastically bounced atoms: EW detuning 400 MHz (solid line) and 900 MHz (dashed line).

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